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PASSIVNAIA I AKTIVNAIA ZASHCHITA PRI KATASTROFICHESKIKH VULKANOV

(Passive and Active Defense from the Catastrophic Eruptions of Volcanoes)

by

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Abstract

A review of major volcanic eruptions in the past and present constitutes the basis for analysis of various types of volcanic activity in the world with a view to pointing out the necessary protective steps to be taken in order to lessen the disaster brought by volcanic eruptions to men and national economy the world over.

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PASSIVE AND ACTIVE DEFENSE FROM THE CATASTROPHIC ERUPTIONS OF VOLCANOES

The Extent of Damage Committed at Catastrophic Eruptions of Volcanoes

The volcanic activity being one of the most destructive phenomena in nature can commit and frequently commits great calamities to men and national economy, and therefore it must be noted that, although not all of the active volcanoes bring devastation, each of them can, nevertheless, be a source of catastrophic events which to a smaller or greater degree are followed by tragic consequences. The volcanic eruptions have a varying force, reaching sometimes a gigantic extent, yet as catastrophic eruptions are usually considered only such as are accompanied by the destruction of men and material values. There are many examples illustrating explicitly the extent of catastrophes.

A certain eruption of Vesuvius occurring in A.D. 79 and burying Pompeii covered with mud the city of Herculaneum and with lava the city of Stabia. Approximately 2 thousand men perished in Pompeii out of 25 thousand inhabiting the city at the time.

As a result of eruption of Volcano Laki in Iceland in 1783, 50% of cattle perished, 76% of horses and 77% of sheep, amounting to 10 thousand cattle, 27 thousand horses and approximately 180 thousand sheep. As a consequence of the following famine, more than 9 thousand men died, i.e. approximately 1/5 of the entire population.

When in 1815 Volcano Tambora erupted in Indonesia, 57,925 men perished, according to a source, but according to other sources, the death toll amounted to 92 thousand men. In addition, vast areas of arable land were destroyed on Soembawa, where the volcano is located, as well as on the neighboring Island Lombok.

As a result of Galoenggoeng's eruption in 1882, 4011 men perished, 114 villages were completely destroyed and 1,668,000 coffee trees were annihilated.

In the same year 100 men perished and many were injured as a result of Merapi's eruption; 4 villages were completely demolished and 4 villages were damanged; in addition 1,260,000 coffee trees were destroyed.

The eruption of Krakatau in 1883, which created a tsunami, brought death to 36,417 men and complete destruction to 165 villages, and partial destruction to 132 villages; further, large areas of arable land were destroyed.

The eruption of Semeroe in 1885 brought death to 70 men and devastation to 66 km^2 of arable land. The eruption of the same volcano in 1909 resulted in the death of 220 men, in complete destruction of 38 villages (1,449 houses) and 11 km^2 of arable land.

Altogether in Indonesia, beginning from 1815, 110 thousand men perished /80
according to a source, but on the basis of other sources the death toll was 145 thousand. Completely destroyed were 610 villages and 4.5 million coffee trees.

The eruption of Pelée in 1902 was accompained by the devastation of the city of Saint Pierre with its 28 thousand inhabitants.

And lastly, quite recently, in 1951, an unexpected eruption of Lamington on New Guinea brought death to 3,000 men.

The enumeration of victims of catastrophic eruptions points out the severe consequences of such eruptions, on the one hand, and the need for protection against the devastating action of these eruptions.

For the time being it is impossible to prevent the occurrence of volcanic eruptions (although there are several theoretic concepts and practical propositions with respect to avoiding the eruptions of Vesuvius) but it is, however, possible to take protective steps against devastating consequences of the action.

Volcanic Phenomena that can bring Catastrophes

Prior to discussing the measures to be taken at active and passive resistance let us first discuss the volcanic phenomena that can bring disaster.

The volcanic activity, as is known, may be classified as effusive, explosive, effusively explosive, extrusive and emissive.

The effusive activity consists of effusion of lava whose chemical and physical properties are of various types.

As is known, there are lavas having a small degree of viscosity, i.e. very fluid, a medium degree of viscosity, i.e. fluid, and having a high

degree of viscosity whose fluidity is restricted.

The first type usually forms a wavy lava known as pahoihoi or is consisting of rather small lumps called aa-lava, the second type usually consists of aa-lava, and the third type consists of sizable lumps known as the lumpy lava of the Santorin type.

The extent of disaster committed by lava flows and the methods of protection against them depend upon physical-chemical characteristics of a given lava and especially upon its viscosity or the inverse magnitude of its fluidity, upon its temperature, mass, i.e. the volume of lava and upon the relief of locality in general as well as upon the angle of slope.

Upon these characteristics depend the speed and distance of movement of lava flow, as well as the pressure force on the obstacles blocking the movement.

The lava of the Icelandic and Hawaiian type usually forms flows of a smaller thickness (tens of centimeters and meters). They have a small degree of viscosity and high fluidity, due to which they can flow for great distances (to several tens and even to 100 km) and circumflow and change the direction of flow when encountering insignificant obstacles. This type of lava can flow over locations whose angle of slope is only 1 to 3°.

The aa-lava is less fluid and moderately viscose, forming usually flows of a greater thickness (meters and tens of meters). The pressure force

on obstacles is considerable. Depending upon the amount of lava and the relief of locality, the material can flow for a distance of several kilometers to several tens of kilometers.

The lumpy lava (of the Santorin type) is viscose, characterized by a low degree of fluidity, very slowly moving and forming thick (several tens of meters) but short (kilometers and less) flows. Due to its thickness the type of lava can exert a great pressure on obstacles.

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Thus, the mass of lava may affect men and various objects of national economy by compressing the buildings, by pouring over the fields and populated areas, by destruction of various obstacles encountered and by its heat setting afire wooden structures and forests, burning the population, etc.

The explosive activity is expressed by ejections of volcanic lumps, ranging from insignificant to large sizes and amounts, of lapilli, sand and dust whose volume may reach several cubic kilometers and the height of several meters to several tens of kilometers. Usually a regular distribution of the products is observed: the lump and lapilli accumulating near the crater, whereas the volcanic sand and dust settles farther from the crater, whereby the settlements of the latter depend upon the direction of crater and that of wind. In calm weather the sand and dust settle around the crater but in windy weather, especially at strong winds, the precipitation form a triangular belt the length of which depends upon the force of wind. If the direction of wind varies with atmospheric layers, the movement and precipitation of volcanic sand

and dust forms a complex pattern depending upon the directions of air currents.

It should be noted that a strong wind, impeding the settlement of volcanic sand and dust on a small area, frequently scatters them over large regions.

The volcanic sand and dust that is formed of a liquid incandescent lava cools off considerably in the air, whereas the volcanic lumps and bombs, which may fly for a distance of several kilometers from the crater cool off little so that only their peripheries are affected, whereas the internal mass remains incandescent.

If such lumps and bombs, fall on buildings, notably on wooden structures and forests, they can set the objects afire. Whereas the volcanic sand and dust can cause disaster mainly with its mass that covers inhabited areas of fields suffocating or poisoning men by the gaseous substances enclosed in the igneous material.

The effusive-explosive activity, consisting of simultaneous or almost simultaneous or alternating effusions of lava and ejections, causes individual formations that are analogous to the effusive and explosive products discussed above.

The extrusive activity is characterised by igneous and incandescent clouds having a straightforward and set directions of explosions, by avalanches and agglomerate flows which are most frequently associated with the squeezing of cupolas.

The direction of inflammable clouds caused by straightforward and set explosions is not subject to the force of gravity. Such clouds, having an initial temperature of about 800°C, move with a speed reaching 150 m/sec. They are characterized by an abundance of "gigantic self-exploding" lumps, sand and gas, as a result of which the incandescent clouds are effective by their mass (bury buildings and men), heat (setting afire buildings and men) and poisonous properties of gases (smothering and poisoning).

The effective field of incandescent clouds is a rather narrow belt reaching a length of 10 km, whereas the field of agglomerate flows is a belt whose length varies from 2 to 4 and 15 to 20 km, the extent of lava formations depends upon the relief of the locality. The movement of the latter is usually subject to the force of gravity and therefore the mass flows down depressions for a distance of several kilometers.

The <u>activity of emissions</u> is characterized by the blowing out of volcanic gases, which reaches a considerable extent at all eruptions except for those occurring in Hawaiian Islands and for the eruptions of Bandaisan type.

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Volcanic gases are blown out of the main mass of lava, but part of them remain in the pores of lava, lumps, lapilli and sand. Gas also is emitted by the latter material, but the process of emission in this case is slower.

In the volcanic gas water vapor predominates, but it contains also HCl, SO_2, H_2S, CO, CO_2 and other gases, which sometimes, and possibly frequently enough, is found in concentrations that are injurious to the well-being of men and animals. The limits of the gas concentrations that could be withstood by men are as follows: 0.1 mg/m^3 of HCl, 0.5 mg/m^3 of SO_2, 0.05 mg/m^3 of H_2S and 6 mg/m^3 of CO. The existence of such amounts of gas and more in the atmosphere is dangerous for men without the use of neutralizing gases.

The explosive, effusively explosive, and partly extrusive types of volcanic activity can create mud streams.

The mud streams are formed: (1) by explosive eruptions from craters filled with water, snow or ice, (2) by subglacial eruptions, (3) by heavy rain during explosive eruptions, (4) as a result of showers washing out the porous sediments on the slopes of volcanoes that have been formed during the preceding explosive and extrusive eruptions, (5) as a result of rapid melting of snow and ice, and (6) as a result of the destruction of dikes of crater lakes. The first three types of mud streams are directly associated with volcanic eruptions, whereas the last three types are only indirectly associated with the eruptions.

The mud streams can cover large areas, progressing to considerable distances (at the eruption of Kotopahi in 1877 to 240 km) and frequently forming fan-shaped streams whose maximum length and width may reach several tens of kilometers.

In the case of underwater eruptions of volcanoes or of volcanoes forming comparatively small islands, tsunami may arise which usually bring great devastations to national economy and men living in coastal areas. The height of tsunami waves may reach several tens of meters. Thus, during the eruption of Krakatau in 1883 the wave height at the coast of Java reached 20 m, but at several points the height was, evidently, greater. The eruption of Severgin in 1934 created a wave 9 m high.

The character of volcanic eruptions varies, depending mainly upon the physical composition of magma, i.e. upon its viscosity, temperature, speed of the emitted products, their volume (lava, lumps and gases) and pressure, notably that of water vapor.

Therefore the volcanoes having a different character or, as is more frequently referred to, having a different type of eruption, cause various disasters.

Thus in the case of the <u>Hawaiian type</u> of eruptions, only the rapidly flowing lavas whose degree of viscosity is low and which belong to pahoihoi and aa types and may sometimes reach great extent in length (tens of kilometers) and area (tens and hundreds of square kilometers) appear to be dangerous.

In the case of the <u>Strombolian type</u> of eruptions the main danger lies in the moderate viscosity of lava which relatively frequently form lava flows of the aa type whose length reaches several tens of kilometers and width, depending upon the relief, varies from hundreds of meters to

several kilometers. A comparatively small danger is inherent in the relatively limited eruptions of volcanic bombs, sand and dust as well as mud streams.

In the case of Volcanic type of eruptions, danger is constituted by the following:

(1) the potent lava streams consisting of lumps and being of the aa and Santorine type and having a limited magnitude not extending several kilometers in length;

(2) the potent ejections of porous volcanic products whose volume /83
ranges from hundreds of thousands of cubic meters to a cubic kilometer;

(3) the potent mud streams reaching several tens of kilometers in length.

In the case of the Plinian type of eruptions, the danger is constituted by:

(1) the colossal eruptions of volcanic sand and dust whose volume may reach several cubic kilometers and

(2) extensive mud streams.

In the case of Ultravolcanic and Bandaisan types of eruptions the deposits of lumps and smaller blocks that cover the area near the crater may constitute a danger (the area depending upon the force of eruption).

In the case of the Peleés type of eruptions, disaster is brought by the incandescent clouds, the avalanches being less dangerous. The area

affected by the clouds ranges from 1 or 2 to 10 km in length and from several hundreds of meters to 1 to 2 km in width.

The movement of avalanches is subject to the force of gravity and the relief of locality, which determines the direction of movement as well as their extent. Only in the case of very steep slopes of volcanoes can the avalanches jump from a ravine to ravine.

In the case of the Kaumai type of eruptions, the disaster is brought by:

(1) incandescent and agglomerate deposits reaching the extent to 20 km;

(2) incandescent clouds whose length reaches to several kilometers;

(3) huge sand and dust clouds whose volume reaches several cubic kilometers;

(4) mud streams several tens of kilometers long.

Summarizing the outlined data, it could be said that the following phenomena act as the sources of disaster brought by volcanic eruptions:

I. Lava formations:

(1) lava streams and fields formed by the basalt lavas of the Hawaiian and Icelandic types; because of their low viscosity and great fluidity of progression at great distances (tens of kilometers) it is known that the longest lava stream reached the length of 130 km;

(2) lava streams formed as a result of the Strombolian type of eruptions consisting of basalt and andesite basalt, which are

moderately viscous, relatively thick and flow to considerable distances from several to tens of kilometers;

(3) lava streams formed as a result of the Volcanic type of eruptions consisting of a viscous lava that is composed of andesite basalt and rhyolite rocks, which are usually massive, the length extended from several hundreds of meters to several kilometers;

(4) the Pelées type lava which is very viscous and cannot flow so that cupolas, pyramids and obelisks are formed. They are dangerous only at the place of eruption.

II. Deposits of volcanic sand and dust which are formed in the case of eruptions of the Plinian, Katmai, Volcanic, Pelées and Stromboline types, whereby in the latter case insignificant deposits are formed, whereas in former cases, i.e. at Plinian and Katmai, as well as at Volcanic, type of eruptions the mass of deposits is great. It may cover large areas depending upon the mass of ejected material, the force of eruption and that of wind. The quantity of deposits depends upon the same factors and upon the size of sand corpusculae.

III. Incandescent clouds and avalanches formed as a result of the Pelée type of eruptions.

IV. Agglomerate streams forming in the case of the Pelée and Katmai types of volcanic activity. /84

V. Volcanic gases constituting a component part of volcanic products that escape at all types of eruptions; their amount is especially great

at the Volcanic and Plinian types of eruptions and very small at the Hawaiian type of eruption. In addition it must be kept in mind that fumaroles, and especially mofettes, that liberate gases before and after eruptions can be dangerous to men and animals.

Forecasting of Volcanic Eruptions

Of great significance in averting the disaster caused by volcanic activity is the forecasting of volcanic eruptions.

Certain achievements have already been attained in this direction, but much research has still to be done in order to clarify all the symptoms of forthcoming eruptions and know beforehand the exact beginning and possibly also the type of eruption.

From this point of view one must study all the types of active volcanoes because each of them has evidently its peculiar properties in addition to the general ones, which give warnings of impending eruption.

On the basis of experience and observations in our country and abroad (R. V. Van-Bemmelen, G. S. Gorshkov, J. Kitsava, M. Takesi, T. Flores, et al) the following phenomena and comparisons can be considered at the present time to serve as diagnostic properties of the imminent danger associated with volcanic activity: (1) intensification and increase in the number of local volcanic earthquakes; (2) volcanic quakes; (3) intensive tectonic earthquakes; (4) sloping of soil; (5) formation of cracks; (6) topographic deformations of locality; (7) local magnetic disturbances; (8) changes in the temperature of lava, fumarole gases

and the water of thermal sources; (9) changes in the composition of the regime of fumarole, mofettes and thermal sources; (10) acoustic phenomena; (11) comparison of the phenomena of the preceding cycles of eruptions of the same volcano; (12) identification of the corresponding phenomena associated with the activity of the neighboring volcanoes; (13) elucidation of the periodicity of eruptions for a given volcano; (14) the formation of lava cupolas and of short lava streams on the peaks of steep volcanoes; (15) accumulation of volcanic sand, dust and sizable blocks on the steep slopes of a volcano.

With a continued study of the symptoms of eruptions and with the improvement of forecasting methods, undoubtedly, also other features will be clarified.

Generally, the forecasting of eruptions depends upon the possibility to identify the phenomena preceding an impending eruption as well as upon the elucidation of the causes of interruptions that are frequently observed at eruptions and can be compared with the preceding eruptions.

It should be noted that, despite the fact that a considerable progress has been achieved (mainly owing to the application of geophysical methods of observations) in this respect during the last years, the problem of volcanic eruptions and their forecasting has, nevertheless, been studied little and insufficiently in its entirety.

At the present time, the volcanic earthquakes are considered to be the most hopeful phenomena of the list.

With respect to the role of the tectonic earthquakes in volcanic eruptions, it could be said that despite the fact that at the present time certain investigations (Orcel et Blanquet, 1953) reject the idea /85
of a direct connection of volcanoes with significant tectonic earthquakes, yet in certain cases such a link is observed. Thus, in 7 days after a very strong earthquake occurring on November 5, 1952, with its epicenter in the Kurile-Kamchatka Trench, i.e. on November 12, the eruption of the Volcano Krenitsin took place; but prior to the earthquake only seldom a weak fumarole activity was observed.

A similar link between the beginning of eruptions and tectonic earthquakes is mentioned by Van-Bemmelen (1957) in the case of certain Indonesian volcanoes.

The formation of cracks, the rise and movement of magma and subterranean explosions cause shocks of varying force, which forewarn of the impending eruption. However, the character of the preliminary quakes and the interval between them and the beginning of eruption varies greatly. Thus for instance, prior to the catastrophic eruption of Vesuvius in A. D. 79, earthquakes began in A.D. 63, continuing with interruptions for 16 years.

The eruption of Paricutin in Mexico was preceded only by local earthquakes which lasted only for 3 weeks.

The eruption of Hekla in 1947-1948, which was one of the greatest eruptions in the twentieth century, occurred almost unexpectedly. Weak shocks were heard for two years and 3 to 4 days before the eruption,

but a considerable increase in force and number was noticed only 20 minutes before the beginning of eruption.

The eruption of the volcanoes Cosegüina and Nicaragua in 1835, which were evidently the most disastrous in America that had occurred in the historical time, was preceded by quakes lasting for a day only.

Prior to the many eruptions of the Volcano Asama in Japan, microquakes were observed for two or three months, but just before the eruption even no quake was detected at the base of the volcano.

Prior to the first eruption of Volcano Bezymiannyi (Bezymyannyy) in 1955, which has been recorded in historical time, earthquakes were observed for three weeks.

All this attests to the complexity of forecasting volcanic eruptions. Evidently, such variations of earthquakes and shocks depend much upon the conditions of the volcanic canal prior to the occurrence of eruption, i.e. whether it is closed or open, upon the viscosity of the rising magma, upon the saturation of it by gases and upon a number of other causes.

For all that, at the present time the most hopeful property of an imminent eruption is the increase in the number of local volcanic earthquakes and volcanic shocks detected usually only by seismographs located near the volcano, on its slopes or not far from them. With the improvement and increase of sensitivity of seismographs, such earthquakes are being recorded from great distances (the quakes of Volcano Bezymiannyi

in 1955-1956 were detected at a distance of 50 km, but the quakes of Volcano Usu at Sova-Sintsan in 1943-1945 were detected from a distance of 69 km).

On the basis of seismograph records the Japanese discriminate several types of volcanic earthquakes that are evidently associated with various volcanic phenomena characterizing various stages of eruptions and various types of eruptions.

Omori (1911) was the first one to elucidate volcanic quakes by seismic studies of eruptions of Usu in 1910. Later volcanic quakes were observed during the eruption of other volcanoes in various countries.

In the USSR, G. S. Gorshkov (1954) observed two types of volcanic quakes associated with volcanic activity of Kliuchevskii (Klyuchevskiy) Volcano. One of the types was evidently caused by the movement of magma in the lower section of volcanic canal, creating weak explosions from the upper /86
sector of crater, the other one was directly linked to lateral eruptions and outflows of lava on the surface.

The eruption was preceded by numerous seismic shocks which paved the way for the rise of magma and its outpour on the surface. Thus the lateral eruptions of the Kliuchevskii Volcano, which belongs to the basalt type, are preceded by a number of seismic shocks and volcanic quakes.

In all probability, other types of volcanic eruptions have a different seismic record attesting to impending eruptions.

It has been observed that some volcanoes begin to "breath" before their eruption, i.e. they rise a little and then sag as a result of increasing and decreasing pressure of magma on the volcanic structure, which changes the slope of its surface that is recorded by instruments.

These phenomena (movement of soil), which are not well pronounced, are observed in large areas around the volcanoes that usually eject more a liquid lava.

On the Hawaiian Islands and in Japan, rapid and abnormal declinations of soil frequently forewarn of the imminent eruptions, especially if they are supported by seismic data. In the case of the Volcano Asama the steepest declination was formed 4 to 6 weeks before the explosive eruptions. In the case of Kilauea and Mauna Loa the determination of declination made possible the forecasting of lava eruptions for a month or even a year ahead.

When the pressure of magma reaches a considerable intensity, tension cracks can be formed on the surface (as for instance on Kilauea in 1955 or on the slopes of Kliuchevskii Volcano in 1956).

At the eruptions of Usu in 1943-1945 the lava rising up the canal gradually deformed the soil, raising it in cupola-shaped mounds and then breaking through them.

Some eruptions are preceded by magnetic disturbances which result either from solidification of the lava that is penetrating into the mass of rocks or, on the contrary, from the warming of lateral rocks when the lava is rising, which causes their demagnetization.

Many eruptions are preceded or accompanied by swift local magnetic disturbances (rapid changes of the inclination and declination). These disturbances are usually ascribed to the effect of the rise of nonmagnetic magma and its gradual crystallisation and, lastly, to the warming of the walls of the canals.

Japanese volcanologists hold the opinion that with the aid of magnetographs located at the right distances to record the swift changes of magnetic characteristics it is possible to identify subterranean movements of magma and thus further the forecasting of eruptions.

It has also been elucidated that the magnetic changes preceding volcanic eruptions are most clearly noticeable at displacements of great volumes of the basic magma that is slowly rising to the surface.

If in these cases the same quantity of magma is rising rapidly, the magnetic variation is difficult to determine long before the eruption with a view to drawing useful conclusions.

In the case of volcanoes where the magnetic changes in the basic magma cannot be detected it is assumed that the rise of magma through the last thousand or several thousands of meters or even several tens of kilo- /87
meters occurs within several minutes or hours before the eruption.

Also the magnetic changes may remain little noticed during the rise of a cooler and more acid magma.

Up to the present time the observations on temperature variations have not yielded satisfactory information needed for the forecasting of volcanic eruptions. In order to collect more material concerning the temperature variation with a view to utilizing it for the forecasting of volcanic eruptions it is necessary to take into consideration the locale where the measurements are carried out: either in the crater, on the slopes of volcanoes or on its periphery; further it should be established whether fumaroles are associated with the crater or with lava flows, whether the rise of temperature is linked with the bottom gases or with the chemical reactions, for instance, with the processes of oxidation.

In the case of Merapi's solfataras, which were located on its periphery; a mutual link between their temperature variations and the eruptions of the volcano were established. The temperature of the solfataras dropped during the eruptions in 1942-1943 (i.e. when the gases freely were passing through the orifice of the volcano), but during the intervals between the eruptions it rose because the main crater was clogged with lava and the gases had to break through the cracks at solfataras, which were located on the periphery of the volcano.

Changes in the composition of gases also can to a degree forewarn of an impending eruption. Thus, before the eruption of Mauna Loa in 1940, H_2S appeared in solfatara gases 25 days prior to the beginning of eruption (Payne, Ballard, 1940). If such phenomena are recorded also for other volcanoes, the variation in the composition of gases can lead

to a valuable method of forecasting volcanic eruptions.

Acoustic phenomena have been little investigated. Perret, however, detected weak humming noises before the eruption of Vesuvius. Such noises can be heard only with the aid of special instruments.

Concluding the review of symptoms of volcanic eruptions, it is necessary to point out that the usefulness of one or the other phenomenon we have discussed in connection with the forecasting of eruptions has not yet been sufficiently investigated.

Thus until such time when a new technique and new methods are developed, the improvement of accuracy in the forecasting of the time and place of volcanic eruptions can be expected from improvement of seismic methods and measurements of declinations and from a wider application of magnetic and, perhaps electric methods, as well as from a more complete and accurate knowledge of the nature of volcanic earthquakes and volcanic life of a given volcano.

It should be added that certain volcanic phenomena that are indirectly connected with eruptions can also be dangerous in addition to the process of eruption. Such phenomena are as follows: (1) formation of cupolas and short lava flows on the edge of the peak of steep volcanoes a portion of which may slide down, creating avalanches and incandescent clouds, and (2) accumulation of a porous material on the steep slopes of a volcano, which may form mud streams during and after rain storms.

Passive Defense from the Disaster Caused by Catastrophic Eruptions

The protection of men and national economy from disastrous consequences of catastrophic eruptions can be either active or passive. The latter type is characterized by the forecasting of eruptions and by determining the areas of volcanoes as in the case of determining the areas of seismic activity.

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Volcanic Areas and Their Basis

A science, notably volcanology, must develop the problem of forecasting the beginning of catastrophic events in order to forewarn of consequences that are to be expected. The analysis of phenomena that have already taken place and have or have not lead to certain disasters is just one aspect of volcanology.

Therefore the development of protective measures based on scientific data and worldwide experience with a view to creating conditions for the safety and protection of men from disaster, as well as from the destruction of material values and their materialization, must be carried out before the menacing events, not after them, as, regrettably, is frequently the case.

The main problem of determining volcanic areas is the clarification and delineation of danger zones for men and national economy with a view to acquainting the population with them and giving recommendations to the corresponding institutes that supervise the displacement of populated areas and structures.

Thus, with the aim of protecting the lives of men and material values in the areas where active volcanoes are found, it is necessary to determine and fix volcanic areas. For this purpose, all the characteristic properties of a given volcano must be taken into consideration, analyzing the possible consequences and favorable factors that would offer protection from the imminent dangers. On the basis of the account, the danger and near danger zones for a given volcano must be pointed out and, in case of need, the means of evacuation of population. Especial attention must be paid to the study of the active volcanoes located near populated centers and large buildings.

The delineation of volcanic areas must be based on the analysis of the following data.

I. A volcano must belong to the category of active volcanoes or be questionable on the basis of certain characteristics.

II. The existing status of a volcano.

III. The structure of volcano and its composition.

IV. The character of volcanic activity in the past.

V. Geophysical data (seismic, magnetometric etc.).

VI. Relief of volcano and its area.

VII. Climatic conditions.

I. The classification of volcanoes into active and extinct has recently caused repercussions. At the present time a volcano is considered to be active: (1) if eruptions occur at the present time; (2) if on the basis of historical documents and books, eruptions have occurred in the recent past; (3) on the basis of legends mentioning volcanic eruptions; (4) on the basis of volcanologic data; (5) on the basis of seismic data; (6) possibly according to magnetic and gravitational data; (7) if a volcano is new: (a) on the basis of determining its absolute age (by the carbonic method), (b) on the basis of archaeological data, (c) on the basis of morphological data.

II. The condition of a volcano at the present time: (1) is active, (2) in the fumarole stage, (3) in the solfatara stage, (4) in the mofetta stage, (5) only hot springs are observed, (6) without visible gas and thermal phenomena.

III. Very important is the determination of the structure of volcanic apparatus and of the composition of its rocks in order to elucidate the character of the occurring volcanic processes and their role in the formation of a given volcano. On the basis of it, the properties of lava and the types of eruptions prevailing during the formation of a given volcano can be determined.

IV. The character of volcanic activity in the past: (1) the character of volcanic formations: lava covering and streams, tuffaceous strata, tufas, deposits of incandescent clouds, avalanches and mud streams; (2) types of eruptions; (3) periodicity of eruptions (rhythmic and non-rhythmic).

V. Geophysical data. Information of changes in space and time of the locations of hypocenters of earthquakes, magnetic activity, etc.

VI. Relief of a volcano and its area. A careful study of the relief of a locale: the presence of barrancas, troughs, valleys, hillocks, ridges, etc. Some of them localize the movement of lava and mud streams, others, however, such as hillocks and ridges that are located on the slopes and at the base of a volcano change the direction of streams or impede and block them.

VII. Climatological conditions. Information of the seasonal character, force and duration of rains, of snow falls and the mass of snow cover, of the predominant direction and force of winds.

On the basis of the data, the danger zones or relatively dangerous localities are determined and delineated on maps. It is also desirable to indicate on a map the possible directions of lava and mud streams, of incandescent clouds and avalanches if they had occurred at earlier eruptions.

If the dangerous and relatively dangerous zones have populated centers, also the roads of population evacuation have to be pointed out on the respective map.

Active Defense

The division into volcanic areas is in essence a passive defense (almost from any type of volcanic eruption), but also active protection from all

the possible disasters resulting from certain types of volcanic eruptions is possible. Active resistance is especially necessary in places where cities and large villages or important constructions, as for instance, water reservoirs, are located as in the case of several islands (Hawaii).

The major measures of active defense are as follows:

1. The bombardment of moving lava streams and crater walls by aircraft or artillery.
2. Creation of dams and other artificial structures.
3. The making of tunnels for letting off the incandescent water currents accumulating in the crater.

Indeed, many other steps will be suggested and, of course, in each individual case it is necessary to decide on what defensive steps serve best the purpose in a given moment.

1. The bombardment by aircraft or artillery can be applied only for changing the direction of lava flow of any type. The purpose can be achieved by bombarding the walls of the cone of orifice, thus changing the direction of lava stream at its source. In other cases the method of bombardment can be used only when lava flows down a definite valley or trench.

At appropriate relief of the slope of a volcano, the flow of lava can be directed into a neighboring trench. By bombarding the cross barriers that are created by lava streams and that change the direction of lava toward vital objects, they are destroyed and lava is channeled into desired direction (Jaggar, 1936).

Difficulties in the application of the method are bad weather, poor visibility observed during many volcanic eruptions, which greatly impedes the execution of the needed accurate bombardment.

2. Protection from the downpour of very fluid lava is achieved by artificial dams which can be readily made of sand, lumps of earth and other porous rocks as well as of soil and the trunks of trees. Such a dam or embankment can be rather easily and rapidly made with the aid of bulldozers, whereby the elevation of embankment need not be higher than the mass of stream, because its objective is to deviate the stream from an area that has to be protected. The main requirement of such a dam or embankment is that it be built at a possibly sharp angle toward the stream and have a constant slope and open way not less than hundreds of meters wide.

Such a method of rechanneling is completely applicable, as experience has demonstrated (MacDonald, 1957), in the case of lava streams of the Hawaiian type. Such embankments can also be used against mud streams, not only in cases when the relief of locality is favorable.

Also other methods of engineering structures are used. Thus, for carrying out special tasks for the service intended to forewarn the beginning of volcanic eruptions in Indonesia, concrete shelters are built in the slopes of volcanoes, which are equipped with the needed instruments and food and, mainly, with oxygen.

In the case of explosive eruptions, sharp roofs from which sand and dust readily slope down serve as a certain protection of buildings from the accumulation of the materials.

3. Fighting against the formation of mud streams associated with the accumulation of great masses of water in the crater, i.e. against the formation of a crater lake, consists of letting down the water. Thus, the drying of the crater is achieved and the possibility of the formation of mud streams is eliminated.

The drying of crater, as it was done in the case of Volcano Kelud, is achieved by making of tunnels down the slope of volcano into its crater, as near to its base as possible.

Lastly, the most effective and radical method securing protection from tsunamis caused by volcanic eruptions, as well as by tectonic earthquakes, appears to be the building of living quarters in areas that lie 20 to 30 m above the sea surface. Of course, also the character of the coast has to be taken into consideration (high, cliffy or low coast, open or almost closed bay, etc.), as well as the depth of the sea; in connection with these factors, the height of the foundations of buildings relative to the sea surface can also be lowered.

Forest zones planted on the coast can lessen the disastrous consequences of tsunamis.

The beginning of strong underwater eruptions or those forming small islands of volcanoes and intensive tectonic earthquakes may be the

forerunners of tsunamis. In addition, frequently but not always, a rapid retreat of water from the coast is observed, the distance being greater than in the case of the usual tides.

Thus, with a view to protecting the lives of men and material values from destructive consequences of catastrophic eruptions, it is necessary to continue a comprehensive study of active and certain extinct volcanoes and delineate without delay the areas of volcanic activity with the objective of elucidating the dangerous and relatively dangerous zones for men and national economy and take the needed protective steps and account for the zones when planning further developments.

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